SETTLEMENT ANALYSIS OF PREFABRICATED VERTICAL DRAIN BY FINITE ELEMENT ANALYSIS FOR TREATED ROAD EMBANKMENT

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Dedicated to my beloved family (Zuraihan,Mohamad Raiyan Haikal &

Nur Rania Qistina),mother, father, lecturers and friends.

Thanks for everything.

May Allah bless all of you

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ABSTRACT

Prefabricated vertical drains with incorporated with preloading has been used widely as a ground improvement technique in geotechnical engineering. Prefabricated vertical drains would be essential to speed up the settlement of subsoil in embankment and soft ground construction. The prediction in the embankment settlement is a critically important issue for serviceability of road, especially the pre-construction settlement. In this study, Finite Element Analysis was done for analysing viability of PVD modelling in subsoil using Plaxis 2D 2016 software. Asaoka's method were used to analyse the field monitoring data that was gathered at a location of an embankments. This method is used to determine ultimate settlement and back calculated coefficient for the horizontal consolidation at a certain location of the embankments. The settlement prediction and the actual measurement at a case study in terms of time to reach 90% consolidation were compared with the field instrumentation results in order to verify the design approach used. Subsequently, the effect of smear disturbance was considered in the parametric study. Various equivalent diameter of influence zone of the PVD are simulated in the modelling of embankment to study the effect of consolidation degree to the drain spacing. Based on the performed analysis, the installation of PVD is proved to improve the rate of settlement and the dissipation of pore water pressures. The rate of settlement decreases as the smear disturbance and drain spacing increase. Modelling of PVD with smear ratio k_h/k_s of 6.0 and drain spacing of 1.0 m shows good agreement with the field measurement.

ABSTRAK

Saliran tegak pra-fabrikasi (PVD) beserta dengan pra-beban merupakan kaedah yang di gunapakai dalam kaedah rawatan tanah di dalam kejuruteraan geoteknik dan bertujuan untuk mempercepatkan proses pengukuhan tanah liat. Ramalan enapan tambakan adalah sangat kritikal di dalam keupayaan sesebuah jalanraya terutama semasa proses pra-pembinaan. Program unsur tak terhingga yang menggunakan program PLAXIS 2D 2016 di gunakan bagi model saliran tegak pra-fabrikasi (PVD). Kaedah Asoaka (1978) di gunakan untuk analisis enapan di tapak bagi pembinaan tambakan jalan. Enapan ramalan serta enapan sebenar di tapak akan di tentukan untuk mencapai 90% pengukuhan tanah yang menggunakan keputusan bacaan pengukuhan enapan di tapak bina. Kesan lumuran juga di ambil kira di dalam kajian parametric. Kepelbagaian diameter imbangan zon terpengaruh bagi saliaran tegak di simulasi dalam tambakan model untuk mengkaji kesan perubahan jarak saliran terhadap darjah pengukuhan tanah. Berdasarkan kajian yang di lakukan, mendapati penanaman saliran tegak akan mengakibatkan enapan tanah dan kadar pelepasan tekanan air liang telah meningkat. Selain daripada itu juga, kadar enapan tambakan berkurang dengan penambahan kesan lumuran dan jarak antara saliran. Permodelan PVD dengan kesan lumuran 6.0 k_h/k_s dan jarak antara saliran 1.0m menunjukan keputusan selaras dengan bacaan di tapak.

TABLE OF CONTENTS

LIST OF TABLES

TABLE NO.	TITTLE	PAGE

LIST OF FIGURES

LIST OF SYMBOLS

S_i	-	Immediate settlement
$S_c(t)$	-	Primary consolidation settlement
$S_s(t)$	-	Secondary compression.
C_s	-	Coefficient of consolidation
C_c	-	Coefficient of compression
σ_0	-	Overburden pressure of soil
U	-	Degree of consolidation
ν	-	Poisson ratio
E	-	Modulus of Elasticity
γ_b	-	Bulk Density
γ_{sat}	-	Wet Density
c_v	-	Coefficient of consolidation for vertical drainage
c_h	-	Coefficient of consolidation for horizontal drainage
k_v	-	Coefficient of vertical permeability
k_{ve}	-	Equivalent vertical permeability
m_v	-	Coefficient of volume change= $\Delta\varepsilon/\Delta\sigma v$
γ_w	-	Unit weight of water
H_d	-	Height of drainage path
T_h	-	Time factor for radial drainage
r	-	Distance from the axis of the pattern of flow lines
r_s	-	Radius of the smear zone
ψ	-	Dilatancy of soil
φ	-	Friction angle of soil
c	-	Soil cohesiveness
q	-	Discharge capacit

C_c	-	Compression index
C_r	-	Recompression index
CR	-	Compression ratio
RR	-	Recompression ratio
d_m	-	Equivalent diameter of mandrel
d_w	-	Equivalent diameter of the drain
D_e	-	Diameter of equivalent soil cylinder
e	-	Void ratio
$F(n)$	-	Vertical drain spacing factor
Fr	-	Well resistance factor for vertical drain
Fs	-	Smear effect factor
Pc	-	Preconsolidation pressure
q_w	-	Discharge capacity of PVD
U_h	-	Degree of consolidation in horizontal direction
β_1	-	Slope in Asaoka's plot
Δ	-	Difference
λ^*	-	Modified compression index
k*	-	Modified swelling index

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The road embankment construction over a soft ground and compressible soil can cause problems to the civil engineer. Road embankment construction over weak saturated clays and silts requires ground improvement to speed up construction and to avoid failure. Without strengthening the ground these soils do not have the strength to support such embankments by itself. For the road embankments construction on soft soil, various factors need to be taken into consideration. The most important factor is in the aspect of time reduction is analysed in regard of the consolidation of the soft subsoil. Prefabricated vertical drains (PVDs) are usually utilized to fasten the consolidation of soft subsoils (e.g. Holtz et al., 2001; Bergado et al., 1996; Chai et al., 1996; Hansbo, 1981; Jamiolkowski et al., 1983; Rixner et al., 1986). The vertical hydraulic conductivity for soft subsoil can be increased using PVD's by micro-sense with above one order of the magnitude. (Bergado et al., 1996; Hansbo, 1981). From the case studies have shown that longer time is required to complete the consolidate on process due to some factors that can affect the performance of PVD. Lee and Chung (2010) proposed that for typical PVD and mandrel size, the diameter of smeared would be approximately 2 – 7 times of the PVD diameter. Soil permeability around the PVD is substantially reduced due to smear effect. The previous study shows permeability ratio for undisturbed soil against remoulded one ranges from 2 to 10 (Hansbo et al., 1981; Bergado et al. 1993). Well resistance is another concern and should be taken into account due to such factors as deterioration of the drain, filter and reduced area and folding of the drain in practice, (Holtz, 1991). However, Lee and Chung (2010) concluded from their study that the effect of drainage resistance is insignificant for q_w> 100 m^3/yr and k_h < 5 × 10-9 m/sec.

The performance of embankment on PVD treated soft ground has been analysed based on analytical method, numerical analysis and field observation data. Finite element method (FEM) is used because it produces less restrictive analysis compared to analytical methods. It also can incorporate elements relevant to the construction such as effects of reinforcement and staged construction (Hird, et al., 1992). This is because it is extremely hard to equate the embankment plain strain analysis essentially with axisymmetric consolidation behaviour of soil which surrounds the single vertical drain. The results of field monitoring and finite element analysis would assist engineers to achieve better understanding regarding true soil characteristics; in contrast with the modelling of finite element. Therefore, this study is carried out to identify the succession of prefabricated vertical drain modelling in soft soil by utilizing finite element method.

1.2 Problem of statement

Stages of construction that are involved in earth embankments is an important geotechnical consideration for a wide variety of civil engineering projects. The stability and deformation of embankments constructed over soft ground must be prospering engineered and analysed. A construction site which consists of mostly thick layered soft soil, the analytical method by Hansbo (1981) can be used. This specific design of vertical drain depends on the installation pattern which is off square grid or triangular grid. Besides this method, the design could also be done by using empirical method or finite element method. Using this method however, depends on the designer proficiency and preference skills.

In behalf of this, the degree of consolidation would combine with the vertical and horizontal consolidation effect. Terzaqhi's one-dimensional consolidation theory can be used to analyse vertical consolidation which is caused by vertical drainage fully. Average horizontal consolidation which is caused by horizontal drainage can be evaluated by solution of Barron (1948) in ideal conditions; which are well resistance and no smear. However, Hansbo (1979) changed the equation to input the well resistance effect and smear effect. This new equation produces a liaison by correlating, consolidation coefficient, drain size, time, the consolidation degree average and drain spacing.

Finite element method (FEM), gives reasonable option for utilization the above traditional technique on vertical drain design and in the expectation of their outcome. The advantages are usually in the application of this method whereby the condition of the subsoil are heterogenous, usually due to the disruption occurred while the drains are being installed. The usage is more applicable when complex situation occurs by Atkinson and Eldred (1982).

1.3 Objectives of study

The aim of this research is to study the effect of consolidation behaviour of embankment on the soft ground with the improvement from Prefabricated Vertical Drain (PVD) Finite element code PLAXIS 2D 2016 are used to simulate a real road embankment on soft ground case research. The research are points out a several objectives which are as following:

(i) To differentiate and estimate settlement of embankment over soft ground treated with preloading and Prefabricated Vertical Drain (PVD) which is obtained from finite element modelling and field instrumentation measurement monitoring.

(ii) To evaluate factor affecting the performance of PVD e.g smear disturbance and drain spacing.

(iii) To create a method for estimating a reliable 90% consolidation settlement utilizing finite element method.

1.4 Scope and limitation of the study

This research is carried out by initiating a road project at Pahang Technology Park, Gambang. The performance assessment was done based on the settlement monitoring data. The constitutive subsoil properties model was done using PLAXIS 2D 2016; which is a 2D plane strain modelling using Soft Soil model and Mohr Coulomb model. In this study, the permeability matching derivation is utilized to achieve the similarities between plane strain condition in Plaxis modelling and axisymmetric behaviour of the vertical drain as done by Lin et al. (2000). Asoaka's method would be used to estimate the final settlement of the settlement data. These data are obtainable from finite element analysis and instrumentation. The comparison would be done between finite element analysis and filed instrumentation monitoring to get the time required for 90% consolidation succession.

1.5 Significant of Study

In this study, it shows the estimation of performance for ground improvement work which is called as prefabricated vertical drains with finite element modelling. It aims to verify and validate the accuracy of estimation from the finite element method by using proper conversion method to obtain a two-dimensional flow which is a representative of its three-dimensional flow. The comparison in between the field monitoring settlement result and finite element analysis would enable the prediction of the time rate settlement for projects in future. Thus, the period of resting for 90% consolidation settlement could be analysed.

REFERENCES

Abuel-Naga HM, Bergado DT, Gniel J. *Design chart for prefabricated vertical drains improved ground* (reference no 2869). *Geotext Geomembranes*. 2015;43(6):537-546. doi:10.1016/j.geotexmem.2015.04.021.

Ali Ar. *Settlement Of Embankment On Prefabricated Vertical Drain Treated Ground* 2010;(1948):1-3.

Ali FH, Huat BK. *Performance of Prefabricated Vertical Drains in Improvement of Malaysian Soft Marine Clay*. 1993.

Aseeja PK. *Modelling Consolidation Behavior of Embankment Using Plaxis*. 2016;7(4):3-8.

Asha BS, Mandal JN. *Theoretical and numerical modeling of laboratory consolidation of marine clay with natural prefabricated vertical drain*. *Electron J Geotech Eng*. 2015;20(9):3829-3838.

Atkinson MS, Eldred PJL. *Consolidation of soil using vertical drains. Géotechnique*. 1981;31(1):33-43. doi:10.1680/geot.1981.31.1.33.

Babu PGLS. Prof. G L Sivakumar Babu Department of Civil Engineering, Ground Inprovement Presentation. 2014.

Balasubramaniam a S, Huang M, Bolton M, Bergado DT, Phienwej N. Interpretation and *Analysis of Test Embankments in Soft Clays with and without Ground*

*Improvemen*t. 1975:1-18.

Bergado D., Mukherjee K, Alfaro M., Balasubramaniam A. *Prediction of vertical-band-drain performance by the finite-element method. Geotext Geomembranes*. 1993;12(6):567-586. doi:10.1016/0266-1144(93)90044-O.

Cascone E, Biondi G. *A case study on soil settlements induced by preloading and vertical drains. Geotext Geomembranes.* 2013;38:51-67. doi:10.1016/j.geotexmem.2013.05.002.

Chai J. Simple method of modeling PVD improved subsoil. *J Geotech Geoenvironmental Eng*. 2001;127(11):965-972. doi:10.1061/(ASCE)1090-0241(2001)127:11(965).

Di Filippo G, Bandini V, Cascone E, Biondi G. *Measurements and predictions of settlements induced by preloading and vertical drains on a heterogeneous soil deposit.* 2016. doi:10.1016/j.measurement.2016.02.068.

Guo X, Xie K, Deng Y. *Consolidation by Prefabricated Vertical Drains with a Threshold Gradient.* 2014;2014(1).

Huan TZ, Abdullah RA, Hezmi MA, Rashid ASA, Alel MNA. *Performance Prediction of Prefabricated Vertical Drain in Soft Soil Using Finite Element Method*. *J Teknol*. 2015;76(2). doi:10.11113/jt.v76.5435.

Huat BBK, Hoe NC, Munzir AHA. *Observational methods for predicting embankent settlement*. Pertanika J secience Technol. 2004;12(1):115-128.

Ikhya I, Schweiger HF. *Numerical Modeling of Floating Prefabri- Cated Vertical Drains in Layered Soil*. 2012:25-35.

Indraratna B. *Recent advancements in the use of prefabricated vertical drains in soft soils.FacEng*.2008;43:29-46.

Indraratna B, Sathananthan I, Bamunawita C, Balasubramaniam AS. *Theoretical and*

Numerical Perspectives and Field Observations for the Design and Performance Evaluation of Embankments Constructed on Soft Marine Clay. *Gr Improv Case Hist Embankments with Spec Ref to Consol Other Phys Methods*. 2015:83-122. doi:10.1016/B978-0-08-100192-9.00003-X.

Indraratna B, Zhong R, Rujikiatkamjorn C. *An Analytical Model of PVD-assisted Soft Ground Consolidation. Procedia Eng*. 2016;143(Ictg):1376-1383. doi:10.1016/j.proeng.2016.06.162.

Iyathurai S. *Modelling of vertical drains with smear installed in soft cla*y. *PhD*. 2005.

Jian C, Venu R. *Prefabricated vertical drains. Gr Improv Third Ed*. 2012:87-168. doi:doi:10.1201/b13678-5\r10.1201/b13678-5.

Kasim F, Marto A, Othman BA, Bakar I, Othman MF. *Simulation of Safe Height Embankment on Soft Ground Using Plaxis. APCBEE Procedia*. 2013;5(January 2016):152-156. doi:10.1016/j.apcbee.2013.05.027.

Lam LG, Bergado DT, Hino T. *PVD improvement of soft Bangkok clay with and without vacuum preloading using analytical and numerical analyses. Geotext Geomembranes*. 2015;43(6):547-557. doi:10.1016/j.geotexmem.2015.07.013.

Li AL, Rowe RK. *Combined effects of reinforcement and prefabricated vertical drains on embankment performance*. *Can Geotech J*. 2001;38(6):1266-1282. doi:10.1139/cgj-38-6-1266.

Li C. *A simplified method for prediction of embankment settlement in clays. J Rock Mech Geotech Eng*. 2014;6(1):61-66. doi:10.1016/j.jrmge.2013.12.002.

Machine FM. *Land Reclamation Using Prefabricated Vertical Drains (Pvd) In Port Of Mombasa* . 2014:105-110.

Manual GD, Technology GI. *Geotechnical Design Manual Chapter 14 Ground Improvement Technology*. 2013:1-112.

Mission JL, Kim H, Won M. *Ground Improvement Optimization with Prefabricated Vertical Drains (PVD) and Surcharge Preloading. 2012:1-4.*

Paul S, Varghese E, Stephen L. *Prefabricated Vertical Drain (Pvd).* 2014;10(2):50-55.

Redana IW. *Effectiveness of vertical drains in soft clay with special reference to smear effect. 1999.*

Reddy SK, Divya P V. *Improving Engineering Properties of Soft Soil Using Preloading and Prefabricated Vertical Drains.* 2013;1(2):8-12.

Rujikiatkamjorn C, Indraratna B, Chu J. *2D and 3D numerical modeling of combined surcharge and vacuum preloading with vertical drains. Int J Geomech*. 2008;8(2):144-156. doi:10.1061/(ASCE)1532-3641(2008)8:2(144).

Rujikiatkamjorn C. *Design procedure for vertical drains considering a linear variation of lateral permeability within the smear zone.* 2009;46(3):270-280.

Saowapakpiboon J, Bergado DT, Voottipruex P, Lam LG, Nakakuma K. *PVD improvement combined with surcharge and vacuum preloading including simulations. Geotext Geomembranes.* 2011;29(1):74-82. doi:10.1016/j.geotexmem.2010.06.008.

Saowapakpiboon J, Bergado DT, Youwai S, Chai JC, Wanthong P, Voottipruex P. *Measured and predicted performance of prefabricated vertical drains (PVDs) with and without vacuum preloading. Geotext Geomembranes*. 2010;28(1):1-11. doi:10.1016/j.geotexmem.2009.08.002.

Shen SL, Chai JC, Hong ZS, Cai FX. *Analysis of field performance of embankments on soft clay deposit with and without PVD-improvement. Geotext Geomembranes*. 2005;23(6):463-485. doi:10.1016/j.geotexmem.2005.05.002.

Shukla AS, Kambekar AR. *Working of Prefabricated Vertical Drain- A Case Study.* 2013;2(8):3675-3686.

Sinha AK, Havanagi VG, Mathur S. *Inflection point method for predicting settlement of PVD improved soft clay under embankments. Geotext Geomembranes*. 2007;25(6):336-345. doi:10.1016/j.geotexmem.2007.04.004.

Stapelfeldt T. *Preloading and vertical drains. Preloading Vert Drains*. 2006:1-27. http://verticaldrain.asia/attachments/article/130/2006-Preloading and Vertical drains (T.Stapelfeldt Helsinki University of Technology)-Wick Drain(PVD).pdf.

Tran TA. *Finite element modeling of peaty soft ground preconsolidated by vertical drains under vacuum-surcharge preloading. :*1-6.

Walker R, Indraratna B. *Vertical drain consolidation with parabolic distribution of permeability in smear zone. J Geotech ….* 2006;132(July):937-941. doi:10.1061/(ASCE)1090-0241(2006)132:7(937).

Whiteley CS. *Determing the end of primary settlement using a simple analytical method progressively calibrated to field settlement data. 2*009.

Yildiz A. *Numerical analyses of embankments on PVD improved soft clays. Adv Eng Softw*. 2009;40(10):1047-1055. doi:10.1016/j.advengsoft.2009.03.011.